Inclined Surface Locomotion Strategies for Spherical Tensegrity Robots

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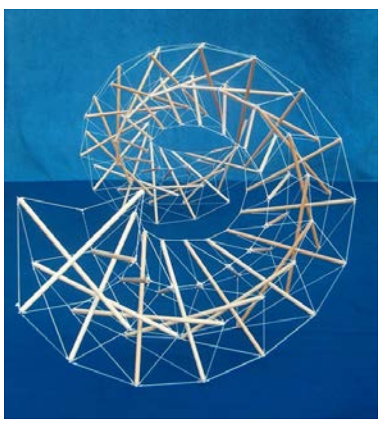
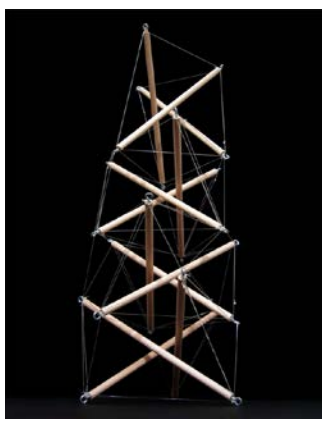
IROS 2017

Background - Tensegrity





- Tensegrity structures are comprised of **rigid bodies** held in equilibrium within a network of **tensile elements**
- Local forces are distributed globally to the entire structure
- These structures are inherently compliant and lightweight

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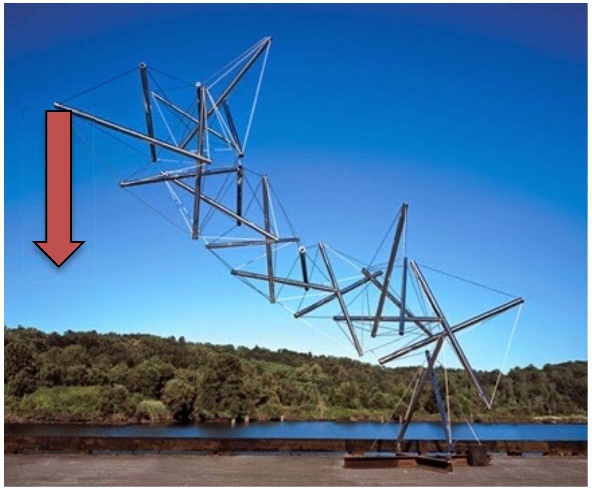

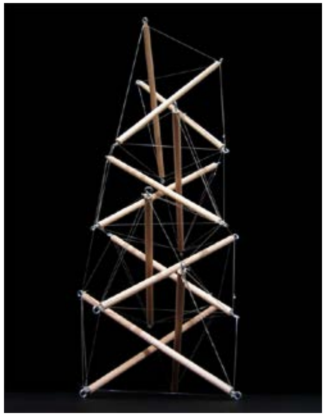

- Tensegrity structures are comprised of rigid bodies held in equilibrium within a connected network of tensile elements
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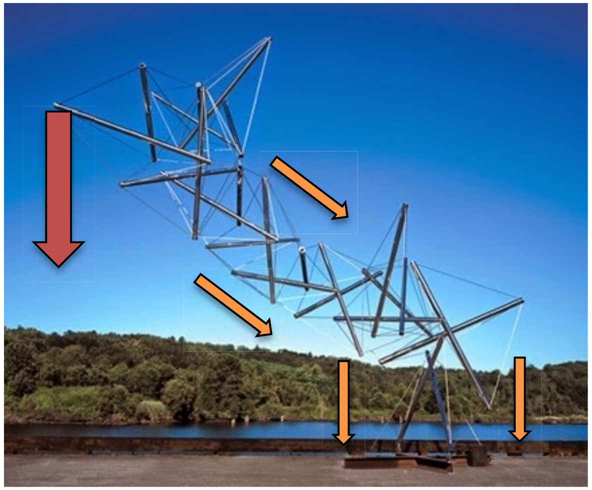

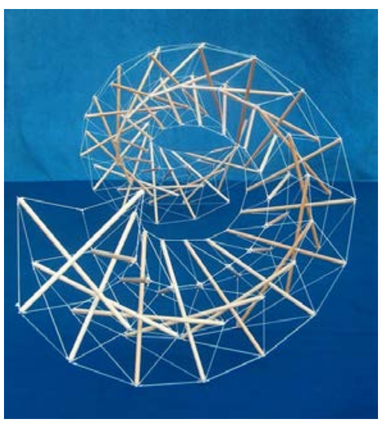

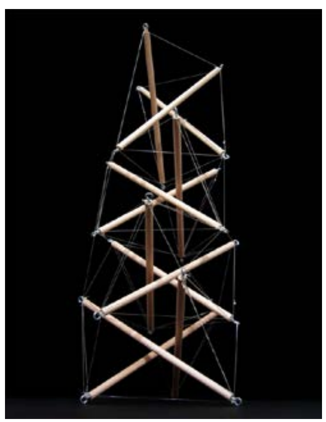

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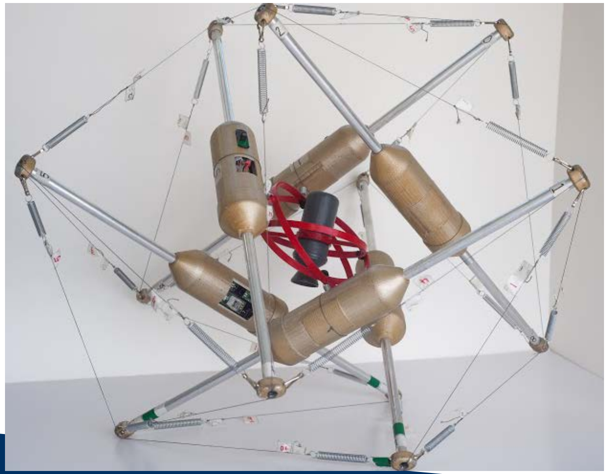
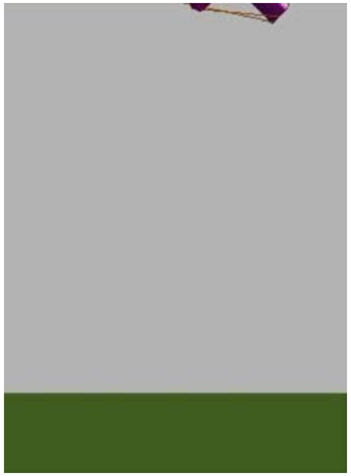
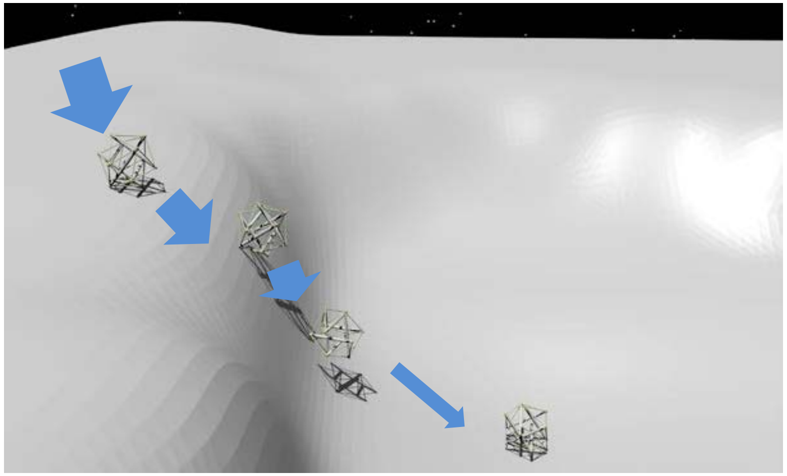
Motivation

- We investigate the potential of tensegrity robots as planetary surface explorers
- Compliant nature of the robot means that the structure can protect a scientific payload that is centrally located
- Needs to be able to traverse unknown and potentially hazardous environments







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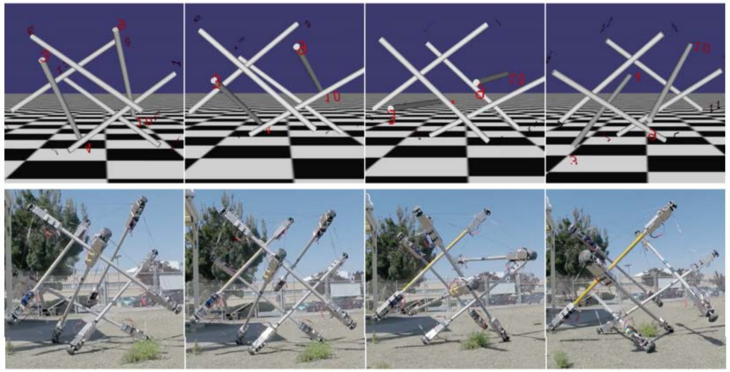
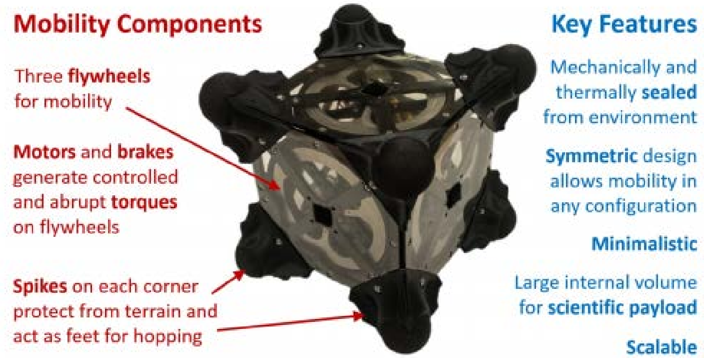
Related Work

- Tensegrity Locomotion Control
  - Bohm et al., '15
  - Zhang et al., '16
- Robotic Incline/Hopping Locomotion
  - Hockman et al., '16
  - Agogino et al., '15



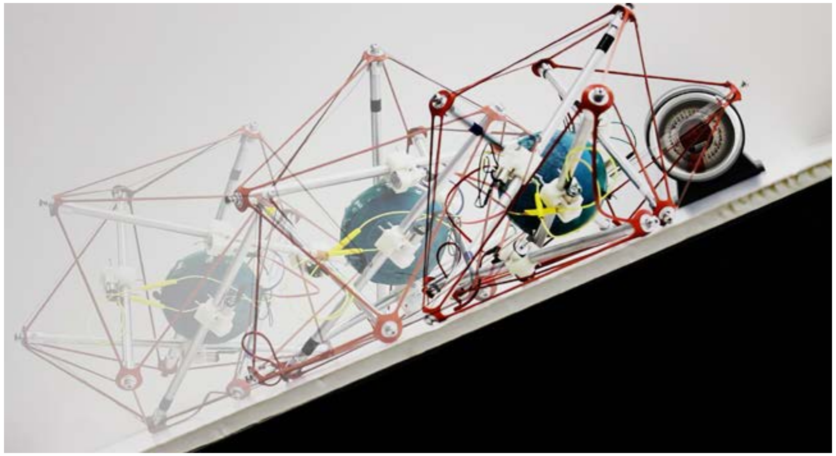
Zhang et al., '15



Hockman et al., '15

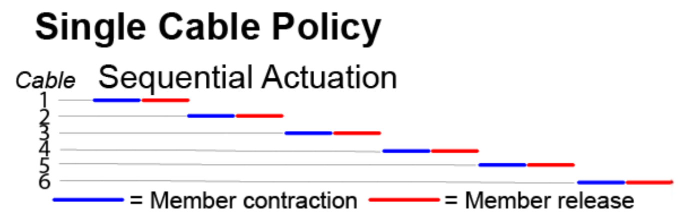
Research Goal

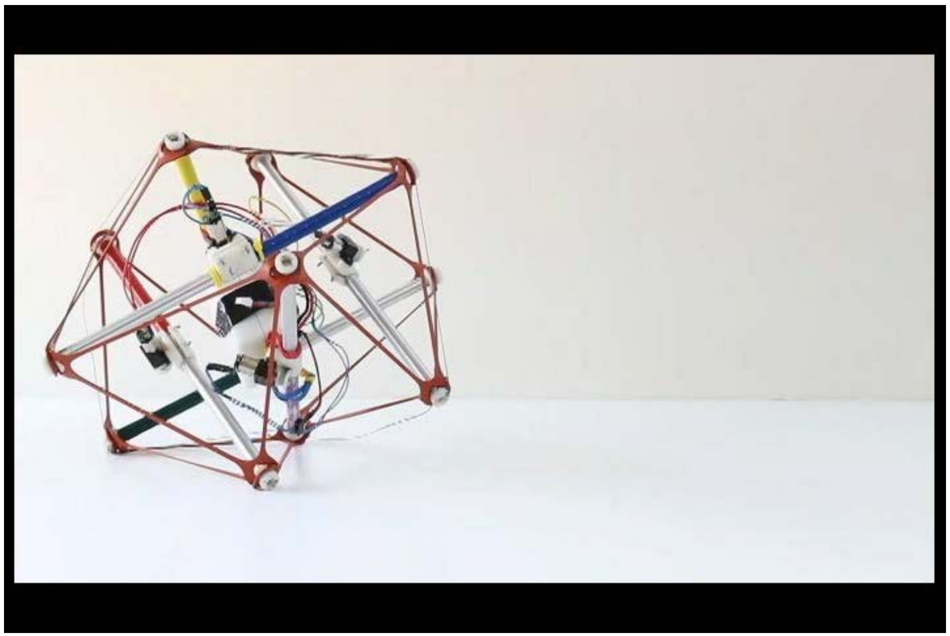
Demonstrate, through both hardware and simulation, the capability of spherical tensegrities to perform uphill inclined climbing



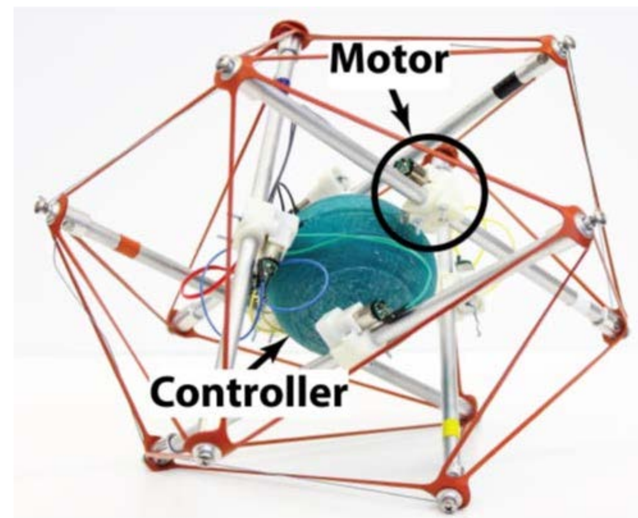
Single-Cable Baseline

- Single-cable actuation policy is used a baseline for uphill climbing performance





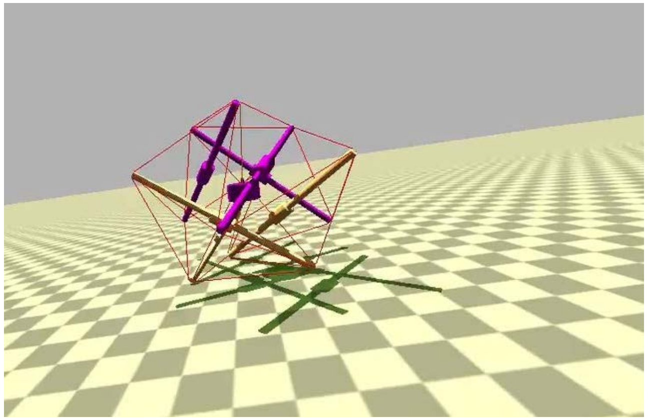
TT-4$_{mini}$ performing single-cable actuation. Source: L. H. Chen et al., "Modular Elastic Lattice Platform for Rapid Prototyping of Tensegrity Robots"

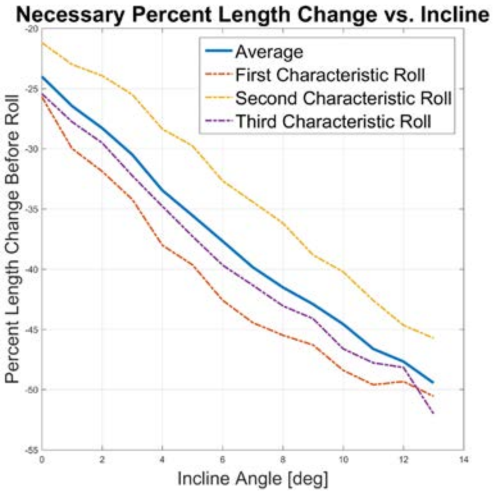


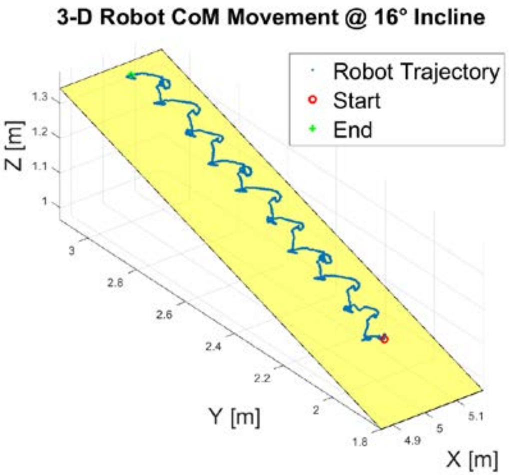
- Central Microcontroller
- 6 Brushed DC motors
- Silicon Rubber Elastomer

Single-Cable Baseline

- Simple single-cable actuation is simulated using the *NASA Tensegrity Robotics Toolkit* (NTRT)
- Model parameters of the TT-4_{mini} were matched in simulation

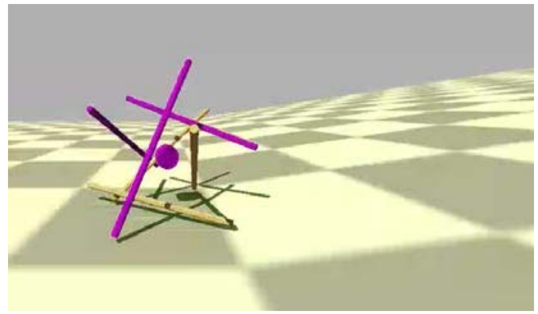




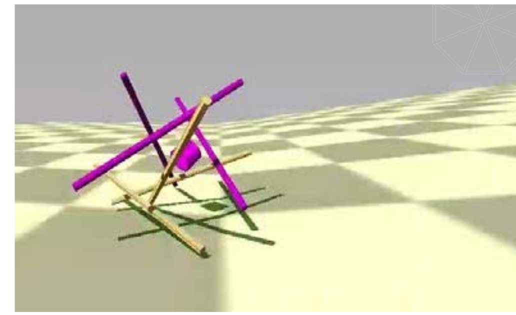


Two-Cable Actuation Policies

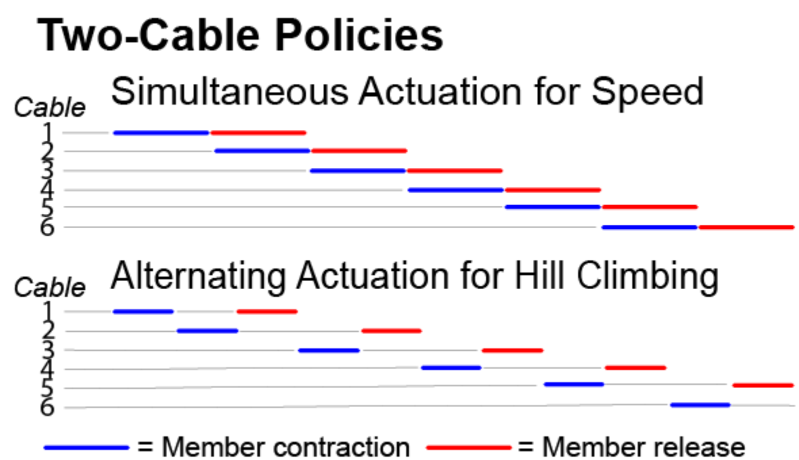
- Utilized NTRT to rapidly test different combinations of two-cable policies
- In simulation, found two different actuation schemes that performed well on very steep inclines



Simultaneous Actuation



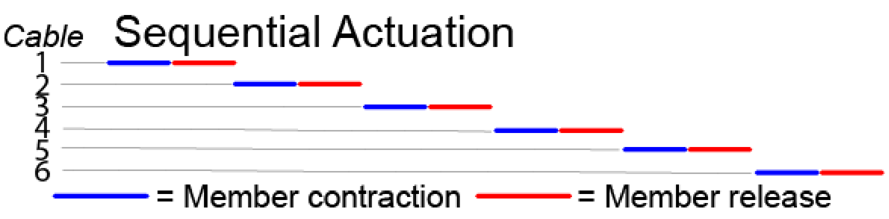
Alternating Actuation



Hardware Experiments Results

Strategy	Avg. Speed@0° [cm/s]	Avg. Speed@10° [cm/s]	Max Incline [°]
Single	3.19	1.96	13
Simultaneous	6.32	4.22	22
Alternating	3.02	2.12	24

Single Cable Policy



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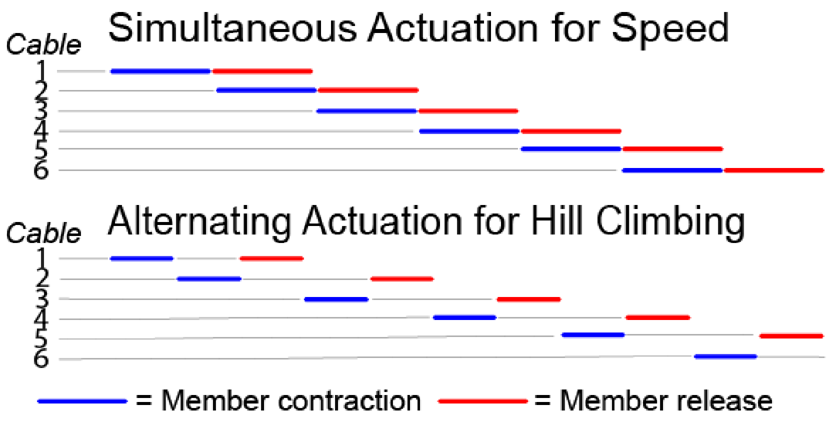

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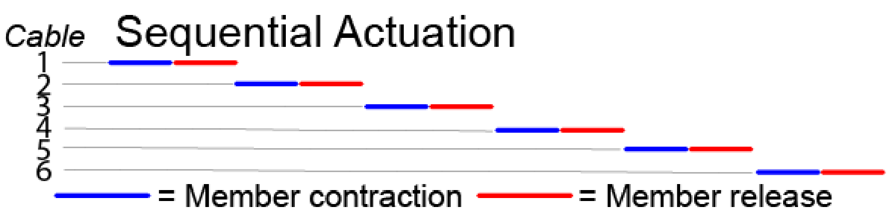

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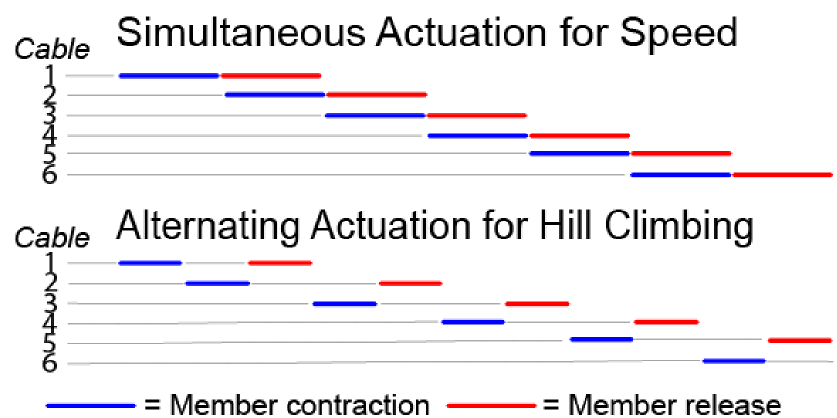

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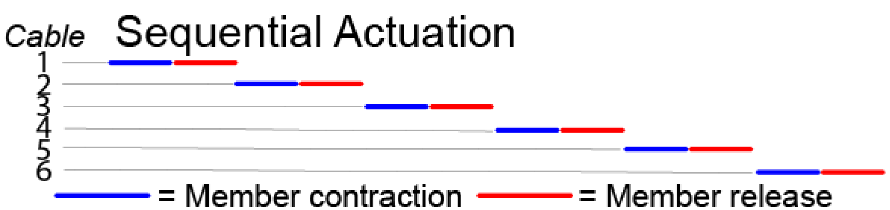

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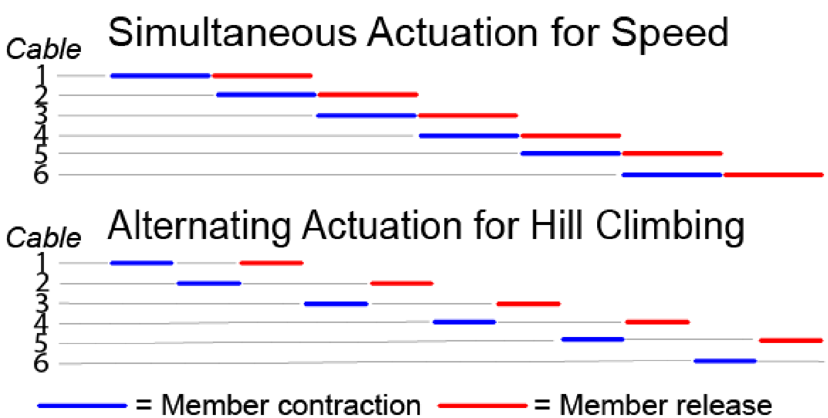

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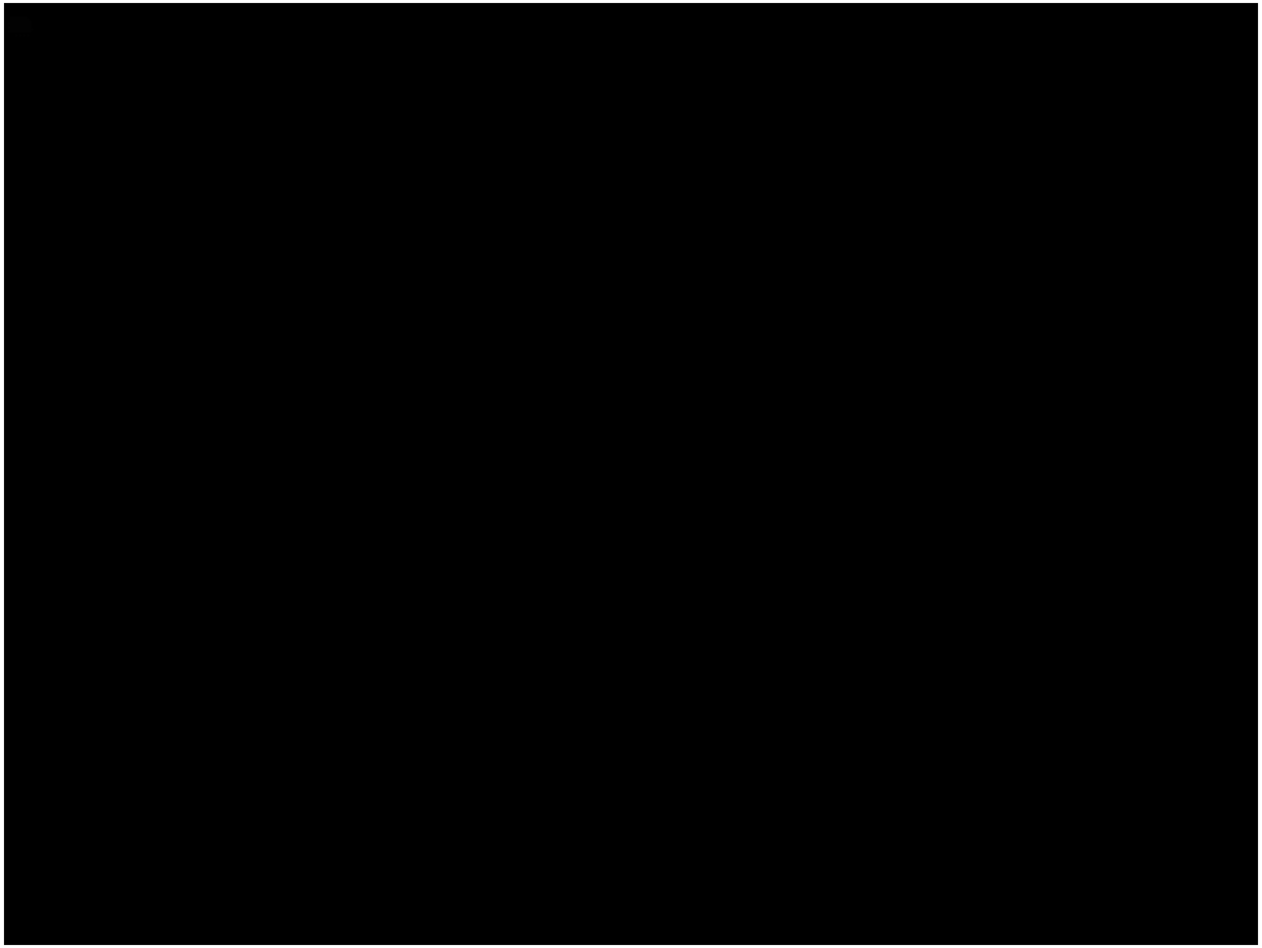

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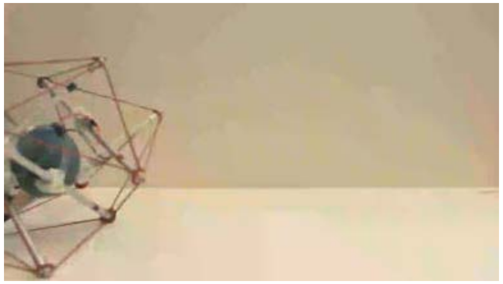
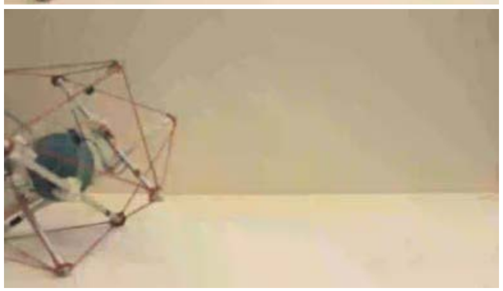
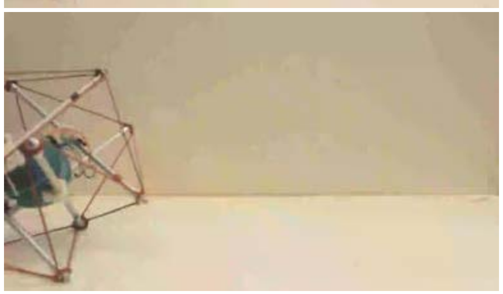


Single-Cable Actuation



Two-Cable Simultaneous Actuation



Two-Cable Alternating Actuation

- Simultaneous Actuation policy demonstrates major improvement in speed
  - Simultaneous Actuation achieved up to 6.32 cm/s
- Mars Curiosity Rover travels at approximately 5 cm/s

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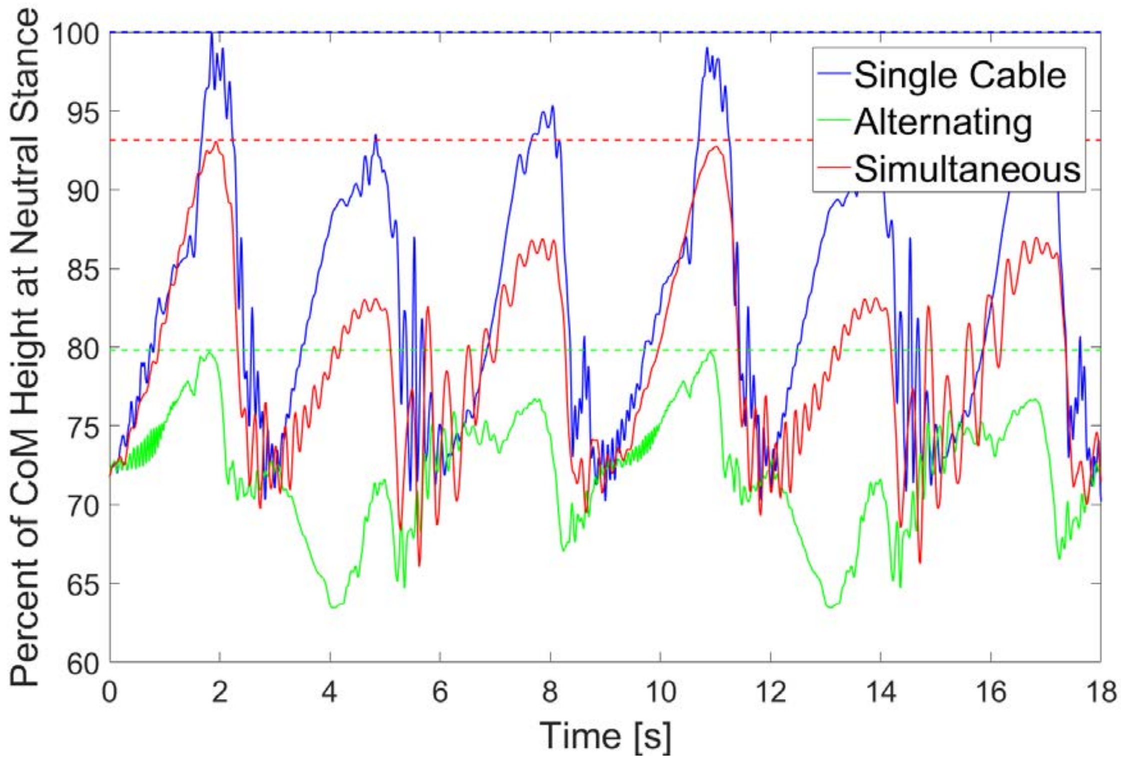
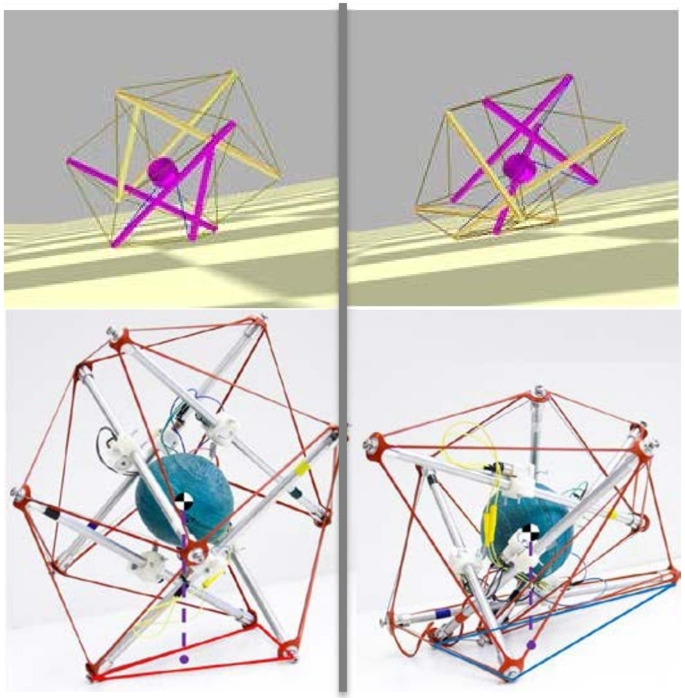
Discussion - Center of Gravity

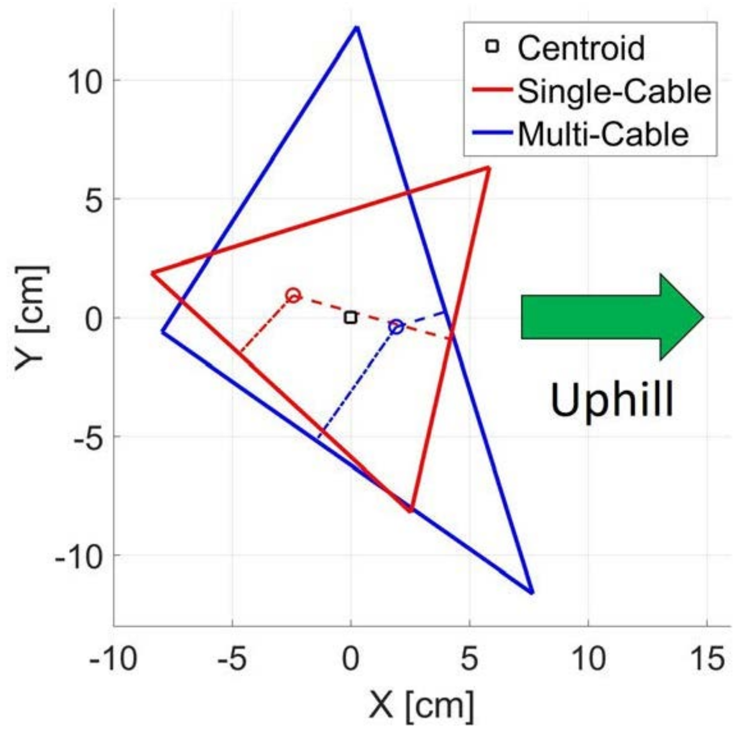


- Two-cable policies both had consistently lower center of gravity
- As expected, lower center of gravity results in greater stability

Discussion - Stance

- Larger supporting base polygon
- Center of gravity is 51.4% closer to uphill edge with multi-cable policy versus single-cable policy



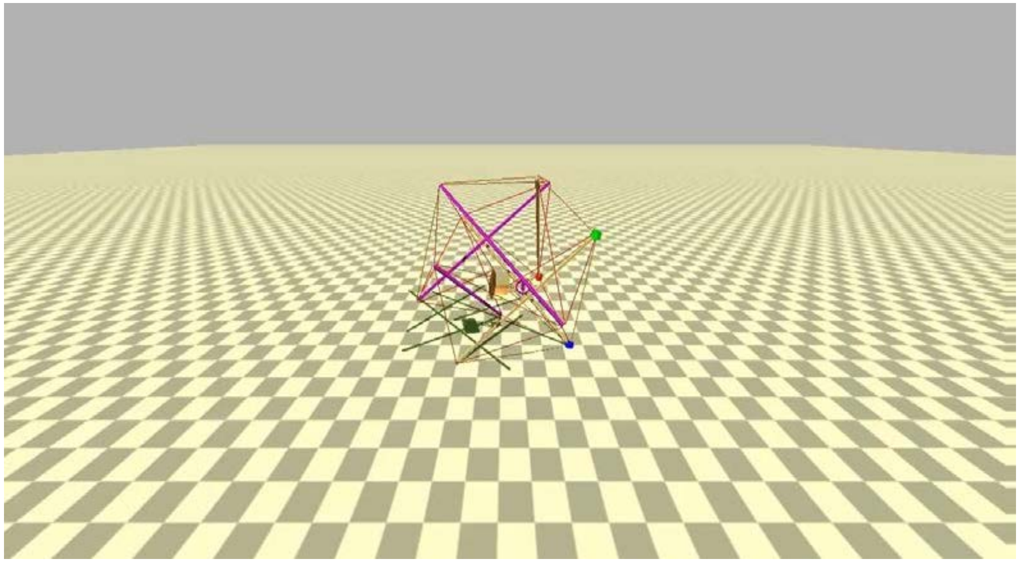


Summary

- Demonstrated uphill locomotion with spherical tensegrity
  - Steepest incline demonstrated in hardware
- Showed simple single-cable actuation can climb up 13 degrees
- Major improvement in performance demonstrated by two-cable actuation policies
  - Lower center of gravity and more stable stance

Future Work

- Multi-cable actuation policies (i.e. all 24 cables actuated simultaneously) seem promising for further improving locomotive capabilities



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Acknowledgements

- Lab website: *best.berkeley.edu*
- Thanks to all of the co-authors
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